Advanced: How Does a Stem Cell "Know" What to Become?

Overview

Ideally, students should approach this lesson with a solid grasp of transcription and translation. These activities tie previous knowledge to gene expression and stem cell differentiation. It addresses the Next Generation Science Standards (NGSS) Performance Expectations HS-LS3-1 and HS-LS1-1. View the standards that apply to this unit.

By viewing animations lacking narration and coming up with explanations, students can visualize and review the molecular processes of **transcription** and **translation**. Using an online interactive simulation, students can practice transcribing and translating a gene down to the level of nucleic acid pairing and amino acid assembly. To apply the concepts of transcription and translation to cellular differentiation, students can simulate **differential gene expression** using free research software called Another Plasmid Editor. In this exercise, "From Genotypes to Phenotypes," students are given one of two environmental signals that act on blood progenitor cells. They translate and transcribe their particular gene target, causing differentiation into either a red or white blood cell.

Through these activities and the homework assignment, students will learn about genotype and phenotype in the context of stem cell differentiation. Even though all cells have the same genotype, a stem cell can differentiate down a certain lineage (phenotype) based on the specific signals it encounters.

Important Terminology

Gene expression: the cellular process of creating a protein, instructed by the sequence of DNA contained within a gene. This process begins with a signal, initiating transcription of a gene. The product of transcription, mRNA, travels out of the nucleus. It interacts with specific protein machinery to transcribe the mRNA sequence into amino acid chains that fold into proteins.

Cell fate decision: the product of differential gene expression, a cell fate decision describes how exposure of stem cells to different external or internal environments can activate transcription/translation of different genes or sets of genes, producing multiple, specific end-stage phenotypes.

For more information, see Teacher Background Information 2 and Teacher Background Information 3 from CIRM model stem cell curriculum Unit 2 and Unit 3.

Outline of Lesson

Discussion of Homework (do as much as time allows)

1. Using their written homework assignments as a guide, ask students to describe their answers.

    a. Compare natural and in vitro fertilization.

2. Ask one or several students to draw their embryonic development diagrams on the board.

    a. Using these diagrams, have different students find the embryonic (pluripotent) stem cells, and then describe where they are and what they can and can't do.

3. For the "brainstorm" homework questions, students can get in small groups to discuss the following question. Each group can come up with an agreed-upon answer and one student can describe the group's ideas to the class.

    a. Why do I have a combination of traits from my parents?

4. For the remaining questions, use guided discussion to dig deeper into the role of DNA in heredity.

    a. How does DNA connect to heredity, where offspring receive traits from parents?
    b. How are stem cells involved in the process of passing traits from generation to generation?

    Allow the students to lead the questioning/brainstorming. Leading questions could be:

        i. What does DNA do?
        ii. What does DNA look like?
        iii. What's the difference between a chromosome, DNA, and a gene?
        iv. Are eggs and sperm similar in DNA content to the fertilized egg? What about between the fertilized egg and somatic (non-stem) cells?
        v. Why are somatic cells (for example, neurons vs. muscle cells) different from each other even though they contain the same exact DNA (genome)?

View "DNA Central Dogma Part 1 - Transcription" [AUDIO BUT NO NARRATION]
During the animation, discuss what is happening. Guide student questions.

1. What is the long pink strand? (DNA)
2. What is the yellow strand? (RNA)
3. What is that thing making the yellow strand?
4. Why was the thing connected to both the pink and yellow strands?

View "DNA Central Dogma Part 2 – Translation" [AUDIO BUT NO NARRATION]
During the animation, students ask questions. Write relevant questions in your notes or on the board.

1. After the Translation animation, go through student questions and have them develop answers using knowledge gained from the Transcription animation.

Off-line computer activity, "From Genotype to Phenotypes"

This activity demonstrates that environmental signals can activate different genes in multipotent cells, causing a cell fate decision. This is also called differential gene expression and is why cells with the same DNA sequence can differ greatly from each other.

1. This activity requires preparation in advance and can be done as individuals, groups, or a teacher presentation.

    a. Teacher preparation instructions
    b. Student activity worksheet

Homework assignment – words in italics are for teacher use in guiding discussion
Read and answer the following questions. If you use internet and library sources, cite them.

1. What is genotype? | *The sequence of DNA in an organism's genome. Transcription of a gene into mRNA and translation of mRNA into a protein creates a cell's or organism's phenotype.*
2. What is phenotype? | *Physical traits, proteins/enzymes, cell behaviors; phenotype is the product of differential gene expression.*
3. How does cell phenotype come from genotype? | *The human genome contains 30,000 genes, but only a subset is expressed in each cell. Through gene expression, transcription and translation of this subset of genes determines how a cell looks and acts—its phenotype.*
4. What dictates cellular potential—for instance, why is an embryonic stem cell different from a somatic cell, like a skin cell? | *The stem cell has a different set of genes that are expressed into proteins than the skin cell because they are exposed to different signals from outside and inside the cells. The stem cell expresses certain "stemness" genes that make it able to proliferate, differentiate, or remain quiet when exposed to certain signals from the environment, whereas the skin cell does not express these stemness genes because they were shut off in the process of differentiation. Cellular potential was demonstrated in the blood progenitor cell activity where erythropoietin caused differentiation into a red blood cell and Granulocyte-Colony Stimulating Factor caused differentiation into a white blood cell.*
5. How does a cell "know" what to become? Brainstorm how you think a stem cell makes a cell fate decision. | *Cell fate means that a stem cell "makes a decision" to differentiate into a more mature cell type. Signals from the environment—chemicals, extracellular proteins/hormones/factors, neighboring cells, the physical environment—converge on the cell, typically activating a signaling cascade that leads to gene expression. These specific proteins change the phenotype into that of a more specialized cell.*
